

LAKE TAHOE ATMOSPHERIC DEPOSITION STUDY (LTADS)

Final Report
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Lahontan Regional Water Quality Control Board
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Tahoe Regional Planning Agency

Prepared by
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Staff Report: Lake Tahoe Atmospheric Deposition Study

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Disclaimer

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Abstract

The world-famous water clarity of Lake Tahoe decreased dramatically during the last several decades. To address the water clarity concern California's Lahontan Regional Water Quality Board (LRWQCB) and the Nevada Division of Environmental Protection (NDEP) are developing the Lake Tahoe Nutrient and Sediment Total Maximum Daily Load (TMDL) for Lake Tahoe. A TMDL is a water quality restoration plan to achieve a specific water quality standard or goal. To meet the need of the TMDL for estimates of atmospheric deposition to Lake Tahoe, the California Air Resources Board (CARB) conducted the Lake Tahoe Atmospheric Deposition Study (LTADS). The primary goal of this study was to quantify the contribution of dry atmospheric deposition to the nitrogen, phosphorus, and particulate matter loading of Lake Tahoe. This report presents CARB's estimates of direct atmospheric deposition to Lake Tahoe. The information resulting from LTADS and similar studies of other pathways inputting materials into Lake Tahoe will be used by the LRWQCB, NDEP, and the Tahoe Regional Planning Agency (TRPA) to develop programs to restore the water clarity of Lake Tahoe.

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Executive Summary

Between the 1960s and the 1990s, the water clarity of Lake Tahoe decreased from 100 feet to 65 feet of visibility into the water at mid-lake. Much of the decreased clarity may be due to increased algal growth. To address the water clarity concern California's Lahontan Regional Water Quality Board (LRWQCB) and the Nevada Division of Environmental Protection (NDEP) are developing the Lake Tahoe Nutrient and Sediment Total Maximum Daily Load (TMDL) for Lake Tahoe. A TMDL is a water quality restoration plan designed to determine the ability of a body of water to accept contaminants without resulting in a reduction in water quality. Materials that can adversely impact water clarity enter the Lake via water runoff, groundwater seepage, shoreline erosion, on-lake activities, and direct atmospheric deposition.

To meet the need of the TMDL for estimates of atmospheric deposition to Lake Tahoe, the California Air Resources Board (CARB) conducted the Lake Tahoe Atmospheric Deposition Study (LTADS). The primary goal of this study was to quantify the contribution of dry atmospheric deposition to the nitrogen (N), phosphorus (P), and particulate matter (PM) loading of Lake Tahoe. Of specific interest are N and P that serve as nutrients to phyto- and zoo-plankton growth and the inert component of PM that scatters or absorbs light. This effort entailed measurement of these materials in the air over the lake and estimation of the airborne material that deposits directly onto the lake surface.

This report presents CARB's methods and estimates of dry and wet atmospheric deposition of N, P, and PM directly to the surface of Lake Tahoe. Potential indirect atmospheric input to the lake (i.e., deposition to the watershed and subsequent transfer to the water) was part of the watershed modeling effort and not directly addressed by LTADS. The LRWQCB, NDEP, and the Tahoe Regional Planning Agency (TRPA) will use the information resulting from LTADS and the other research programs to develop programs to restore the water clarity of Lake Tahoe.

LTADS was a multi-million dollar effort with contributions of funds and effort by the United States Environmental Protection Agency, USDA Forest Service, Tahoe Research Group (TRG), NDEP, LRWQCB, and TRPA, as well as CARB's Monitoring & Laboratory, Planning & Technical Support, and Research Divisions. Research groups from the Berkeley, Davis, Riverside, and San Diego campuses of the University of California, the Desert Research Institute (DRI), and the National Oceanic & Atmospheric Administration also contributed their expertise. Planning for the study began in the Fall of 2001. By the end of 2002, several new air quality or meteorological monitoring sites had been set up in the Lake Tahoe Basin and at Big Hill, a well-exposed site on the western slope of the Sierra Nevada to the west-southwest of Lake Tahoe. Collection of gaseous and particulate ambient air quality and meteorological data continued through the end of 2003 at all sites and a subset of parameters at some sites into the spring of 2004. Air quality and meteorological measurements have routinely been made for many years at a limited number of locations in the Tahoe Basin and enhanced sampling has occurred during short-term field studies. However, the combined sampling efforts

of the ARB, TRG, TRPA, DRI, etc. during LTADS resulted in a large set of contemporaneous air quality and meteorological data representing conditions in the Lake Tahoe region during four seasons. In addition, to support the development of an improved emission inventory for the Tahoe Basin, studies were conducted to measure emission activity factors critical sources such as road dust and smoke (from residential and prescribed wood burning).

The LTADS approach for estimating dry atmospheric deposition to Lake Tahoe was based on seasonal-average N, P, and PM mass concentrations being apportioned, based on mass, to hourly concentrations, which then were merged with day- and hour-specific deposition velocities to provide deposition estimates. The wet deposition estimates were based on a simple conceptual model that used seasonal air quality concentrations in four quadrants of the Tahoe Basin, precipitation frequency, and various assumptions regarding mixing heights, washout efficiency, etc. The estimate of wet deposition is for the year 2003, which allows direct comparison with field measurements obtained with surrogate surface deposition samplers and with the LTADS dry deposition estimate. However, precipitation frequency data indicate that the number of days with measurable precipitation were greater than normal during 2003, although the total precipitation amounts were less than normal. *Based on the precipitation frequency in 2003 compared to the climatological norm, wet deposition in a normal year would be about 70% of the 2003 estimate presented in this report.*

The LTADS estimates of annual direct atmospheric deposition of N, P, and PM to Lake Tahoe (central with upper and lower bounds) are presented for both dry and wet deposition in **Tables ES-1 and ES-2**, respectively. CARB staff prepared these final estimates of direct atmospheric deposition to Lake Tahoe based on comments from peer reviewers and additional refined analyses. The updated analyses included improved formulation of the deposition velocity equations and improved characterization of depletion of PM over the Lake, etc. The seasonal deposition estimates (summarized in **Figure ES-1**) and the characterization of the emission sources and atmospheric processes at work in the Tahoe Basin will help to guide the development of potential control measures to reverse the declining water clarity for which Lake Tahoe is famous. Background information, approaches, assumptions, and analyses leading to these atmospheric deposition estimates are presented primarily in Chapters 4 and 5 of this report.

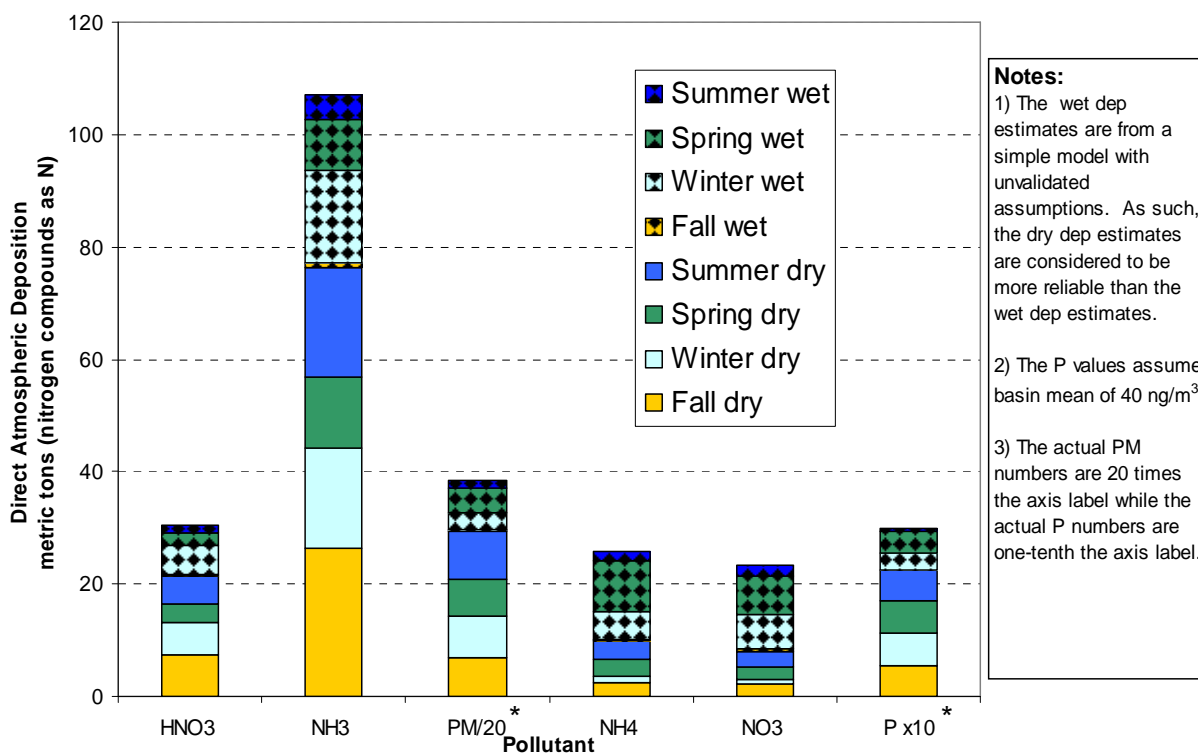
Table ES-1. LTADS Estimates of Annual Dry Atmospheric Deposition to Lake Tahoe (metric tons/year)

Pollutant	Lower Bound	Central Estimate	Upper Bound
N (NH_3 , NH_4^+ , HNO_3 , NO_3^-)	70	120	170
P (P, PO_4^{-3})	1	2	3
PM (in 3 size ranges)	360	590	860

Table ES-2. LTADS Estimates of Annual Wet Atmospheric Deposition to Lake Tahoe*
(metric tons/year)

Pollutant	Lower Bound	Central Estimate	Upper Bound
N (NH_3 , NH_4^+ , HNO_3 , NO_3^-)	30	70	150
P (P , PO_4^{-3})	0	1	2
PM	70	165	315

* The wet deposition estimates are based on a simple analysis with realistic but unvalidated assumptions.

Figure ES-1. LTADS Central Estimates of Seasonal Total Atmospheric Deposition to Lake Tahoe
(metric tons/year)*

* Note adjustment to PM and P values. Actual PM dep is 20 times greater and actual P dep is 10 times less than indicated on Y-axis.

The LTADS total annual atmospheric deposition estimate for nitrogen is comparable with previous deposition estimates from water-based surrogate surface deposition samplers operated by TRG.

Due to the difficulty and large uncertainties associated with the measurement of phosphorus in particulate matter, the CARB analysis provides phosphorus deposition estimates that are conservatively based on assuming a spatially and temporally constant phosphorus concentration of 40 ng/m³. The central estimate from LTADS of total annual phosphorus deposition to the Lake is less than that based on surrogate surface samplers operated by TRG. A factor in the discrepancy between the CARB and TRG P deposition estimates is that CARB's air quality measurements do not include the very largest particles, such as those associated with soil, plant detritus, and pollen near sources, which the TRG surrogate surface deposition sample would include. The phosphorus measurements from TRG's dry bucket samples, when the field notes indicated pollen was present, suggest that natural sources may be a significant source of phosphorus input to the lake. With adjustment for these highly impacted samples, the TRG estimate of total phosphorus deposition is comparable to, but still higher than, the LTADS estimate.

The LTADS estimate for the atmospheric deposition of PM is the first ever developed for Lake Tahoe. The estimates of direct atmospheric deposition of PM mass to the lake include three size fractions: PM_fine (diameter < 2.5 µm), PM_coarse (2.5 µm < diameter < 10 µm), and PM_large (diameter > 10 µm). The estimates are for atmospheric PM. *Because about 20% of the PM mass is water soluble, it will be necessary for water quality scientists to account for subsequent losses and changes in particle size and composition prior to considering their optical effects on water clarity.*

The following list summarizes the major findings from LTADS. Some findings are new but many are confirmatory of previous measurements, hypotheses, conceptual models, and findings.

- 1) Atmospheric deposition is difficult to estimate precisely. It is somewhat reassuring that different approaches have yielded comparable results for the direct atmospheric deposition of biological nutrients in 2003, nitrogen (~200 metric tons) and phosphorus (~5 metric tons). The wet/dry bucket (surrogate surface) sampler at the Wallis Tower site is not a representative sampling location due to extensive and nearby presence of trees.
- 2) About three-fourths of the deposited N is in gaseous form (~150 metric tons in 2003), primarily ammonia but also nitric acid. The differences in ammonia concentrations measured at two nearby sites but on opposite sides of Highway 50 indicate that motor vehicles could be a major local source of ammonia emissions.
- 3) Phosphorus is very difficult to measure at the low concentrations (and with interfering pollutants) found at Lake Tahoe.
- 4) The mass of atmospheric PM directly deposited into Lake Tahoe in 2003 was conservatively estimated at ~1200 metric tons (includes soluble ions).
- 5) PM larger than 10 µm tends to deposit near its sources as evidenced by the small difference in ambient PM₁₀ and TSP concentrations at sites not impacted by local sources and by road dust experiments making particle count measurements at various distances from a roadway source.

- 6) PM_{2.5} concentrations tend to be relatively low and uniform around the Basin while larger particles exhibit a much larger spatial and diurnal variation associated with population and motor vehicle activity.
- 7) Uncertainties remain regarding transport of materials aloft, above the surface layer. Ozone data collected during LTADS confirm that surface layer transport of ozone and other reactive species (e.g., HNO₃, NH₃, nitrates) is infrequent and of relatively low magnitude due to meteorological processes (e.g., wind flow reversals, transport speeds, mountain barrier, limitations on vertical mixing, deposition, chemical reactions). However, limited measurements of conditions aloft by an aircraft indicate an enhanced background level of ozone and a relatively uniform vertical distribution of ammonia concentrations.

The data, estimates, conclusions, and implications from the Lake Tahoe Atmospheric Deposition Study are now informing the development of the Lake Tahoe Water Clarity TMDL by the California and Nevada water quality planners as well as the environmental threshold planning by the Tahoe Regional Planning Agency.

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Appendix L – Estimates of Dry Deposition without Depletion over Lake Tahoe

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Chapter 8 (Conclusions and Recommendations) – Eileen McCauley, Ash Lashgari

Appendix A (Comparison of Surrogate Surface Methods of Measuring Dry Deposition) – Leon Dolislager

Appendix B (Analysis of Historical Aerosol Data) – Tony VanCuren

Appendix C (Comparison of PM Sampling Methods) – Leon Dolislager

Appendix D (Additional Meteorological Data Summaries) – Leon Dolislager

Appendix E (Java Code used in Dry Deposition Model) – Jim Pederson

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Appendix K (Additional Reading and Resources) – Leon Dolislager

Appendix L (Estimates of Dry Deposition without Depletion over Lake Tahoe) – Jim Pederson

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